2

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WIND MEASUREMENT ACCURACY OF A LORAN RADIOSONDE

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A comparison of winds obtained using a Loran radiosonde system developed at Phillips Laboratory and winds derived using radar tracking of targets attached to the radiosonde balloon train are presented. The tests involve 10 ascents with dual Loran ground stations on most flights and dual radar tracking on two flights. The tests wer performed at the Goddard Space Flight Center/Wallops Flight Facility in June 1990. The radiosonde is sufficiently accurate (0.32 m/s) to evaluate a wind profiler that has an error budget of 1.0 m/s. The wind profiler has been proposed to satisfy Day of Launch missile range wind measurement requirements.

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Contents

Illustrations

Tables

Preface

Frank Schmidlin from NASA Wallops provided guidance in setting up the field experiment, was responsible for providing the range tracking, and provided specialized processing of the radar data, which facilitated the intercomparison with the radiosonde data. I thank him for his efforts.

Wind Measurement Accuracy of a Loran Radiosonde

1. INTRODUCTION

The Atmospheric Sciences Division of Phillips Laboratory has begun a program to see if wind measurements made by a wind profiler could satisfy day of launch (DOL) missile-range wind requirements. The wind profiler selected for this was one of the 403 MHz production units procured by NOAA from the Unisys Corporation.

The first step in the program was to choose and evaluate a standard against which the accuracy of the wind profiler would be compared. A Loran type radiosonde system was selected as the comparison standard for several reasons; accuracy, cost, portability, and availability. The results of the test series in which the accuracy of the Loran sonde system was measured is the subject of this report.

The missile range requires an accuracy of 1 m/s with a resolution of about 200 m so it is important that the accuracy of the testing system be significantly better than this. The accuracy of the Loran system is predicted to be < 0.5 m/s in the Sudbury area where the profiler is to be located and also in the Wallops Island area.

There were a couple of Loran radiosonde systems available commercially but we chose to assemble our own from off the shelf hardware. This allowed us to customize the system through

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software development to satisfy our specific requirement. In addition it allowed us to build two systems with an outlay of about a third the cost of buying two complete sonde systems.

The Loran systems are portable in that they do not rely on antenna pointing to derive winds as does radar. Consequently, a Loran system does not need a large antenna/pedestal or elaborate siting procedures.

Since the software programs used to track the Loran signals and to derive winds were new, it was necessary to test the system against a known tracking system to assess its accuracy. This was accomplished at Wallops Island using Radar 5, an AN/FPQ-6 tracking radar, and Radar 3, an AN/FPS-16 tracking radar, in June 1990.

2. DESCRIPTION OF THE LORAN RADIOSONDE SYSTEM

A block diagram of the system is shown in Figure 1. The component parts are all off the shelf or were available in-house. The receiver and pre-amp are Communitronics MR14 and MR14A respectively, which were available in-house. The meteorological processor is a Vaisala PTU Processor PP11. The Loran tracker is the tracking cards from a Viz Manufacturing Corporation W9000 system. The antenna was a simple corner reflector (≈13 db gain) available from previous work. The system uses an Arrowrotor antenna rotator from Radio Shack. The PC/AT was a 286 clone from the government desktop contract.

The system uses a Vaisala RS-80-15L sonde . The sonde transmits a 403 MHz FM modulated signal. The Loran (100 kHz) and the met data (8-10 kHz) are frequency multiplexed. The met data band is also time multiplexed between pressure, temperature, humidity, and some calibration data. The receiver demodulates the data and separates the met data and the Loran data. The met data is provided to the met data processor which converts it to engineering units using calibration data from a paper tape provided with each sonde. The met data processor then outputs this data as an RS 232 data stream to the PC/AT. A complete frame of met data requires approximately 1.2 seconds. The Loran data is provided by the receiver to the Loran tracker, which converts it into time delays (TD's) and provides these TD's as an RS 232 data stream to the PC/AT.

The PC/AT ingests Loran TD's every 2 seconds. It ingests all the met data but uses only the latest met data available every 2 s. Both the 2-s met and the 2-s Loran data are written to files on floppy disks. These can be used to rerun the flights with different parameters, such as Loran stations, smoothing interval, and wind calculation interval. The system also uses the data to generate a 6-s data file that contains time of flight (s), pressure (mb), alt (km), temp (°C), humidity (%RH), X-distance east (km), Y-distance north (km), u-velocity east (m/s), and v-velocity north (m/s). These 6-s data are written to the floppy disk and are also kept in active memory for plotting during flight.

During flight the operator has the choice of two types of displays. One has two plots on the screen together with a data window that continuously displays the last seven 6-s data frames and a menu window. The two plots can be changed by the operator to several choices; T,H versus alt,

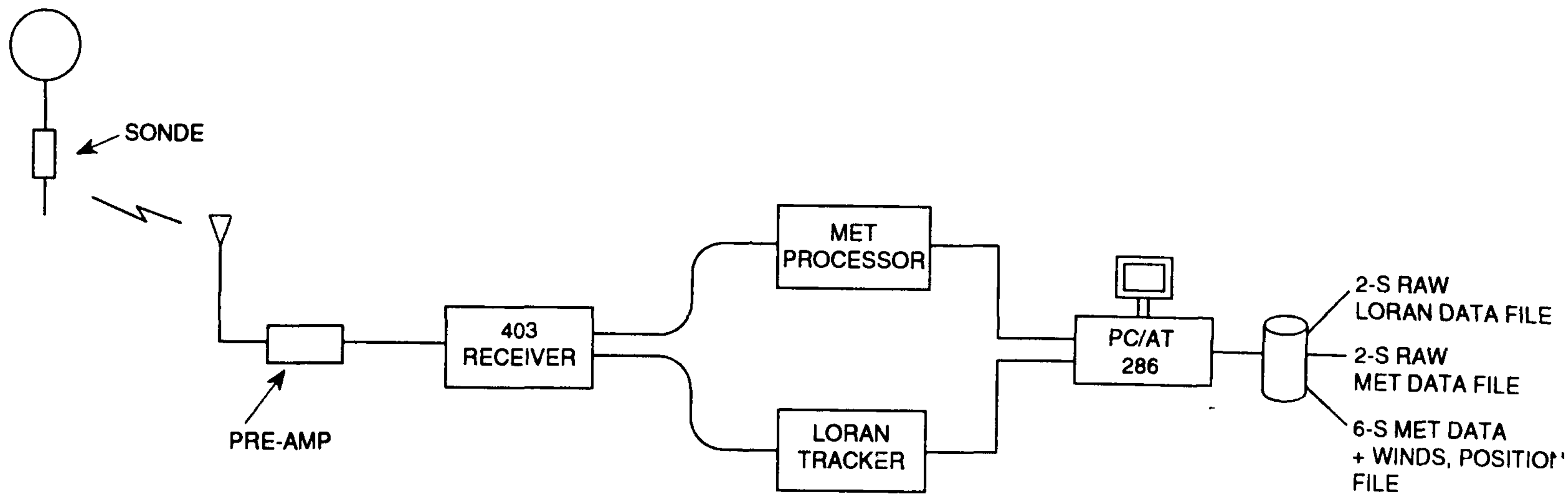

Figure 1. Loran Radiosonde System

u,v versus alt, X versus Y, P,T,H versus time, X,Y versus time. The other display has only a single plot on the screen which can be any of the plot choices given above.

3. TEST SERIES

The tests were performed at the Wallops Island Test Facility on 5, 6, and 8 June 1990. Ten ascents produced useful results. Two additional ascents were not used due to instrumentation difficulties. Table 1 gives details of the ascents used in the data analysis. Ascents 1-8 were tracked by two Loran ground stations. Ascent 6 had two radiosondes separated horizontally by an 8-ft pole and offset in frequency so that the Loran ground stations could track different sondes. The other ascents had the Loran ground stations tracking the same sonde. Ascents 9 and 10 had single Loran ground stations due to a malfunction in the No.1 ground station. Ascents 8 and 9 were tracked by two radars.

Table 1. Test Summary

Date	Time	Ascent No.	Sonde No.	Sonde System	Radar	
6/5/90	1310	1	1	1	5	
			1	2	5	
6/5/90	1645	2	2	1	5	
			2	2	5	
6/5/90	1830	3	3	1	5	
			3	2	5	
6/6/90	1309	4	4	1	3	
			4	2	3	
6/6/90	1438	5	5	1	3	
			5	2	3	
6/6/90	1710	6	6a	1	5	double sonde on bar
			6b	2	5	
6/6/90	1858	7	7	1	5	
			7	2	5	
6/8/90	1601	8	8	1	3,5	double radar track
			8	2	3,5	
6/8/90	1721	9	9	2	3,5	double radar track
6/8/90	1838	10	10	2	3	

4. DATA ANALYSIS

The wind profiler produces a wind measurement for each 250 meter increment of height from 500 m above the surface to 16250 m. These winds are derived from radar returns from approximately 350 m of altitude in the lower beam (500 m to 9500 m) and from approximately 1050 m of altitude in the upper beam (7500 to 16250 m). I decided to analyze the test data using the difference in position data 1 min apart, which averages the sonde motion during this interval. Since the radiosonde rises approximately 350 m/min, this matches the altitude interval of the radar returns contributing to the winds in the lower beam of the profiler. Modifying this finer scale data to reflect the interval in the upper beam is simply a matter of vectorially averaging 3 min of the 1-min data.

The radar winds were determined every 6 s by taking the difference in position data 1 min apart. The position data used was the result of averaging 5 s of 1-s data (51 data points).

$$X_{rad}(i) = \frac{1}{51} \sum_{j=-25}^{25} x_{rad}(j) \tag{1}$$

$$Y_{rad}(i) = \frac{1}{51} \sum_{i=-25}^{25} y_{rad}(j) \tag{2}$$

where $X_{rad}(i)$, $x_{rad}(j)$ are distances east of the launch point and $Y_{rad}(i)$, $y_{rad}(j)$ are distances north of the launch point. $x_{rad}(j)$ and $y_{rad}(j)$ are obtained every 0.1 s and $X_{rad}(i)$, $Y_{rad}(i)$ are obtained every 6 s.

Then

$$u_{rad}(i) = X_{rad}(i+5) - X_{rad}(i-5) \tag{3}$$

$$v_{rad}(i) = Y_{rad}(i+5) - Y_{rad}(i-5)\ . \tag{4}$$

The radiosonde winds are derived in a similar manner.

$$X_{sonde}(i) = \sum_{j=-5}^{j=5} x_{sonde}(j) \tag{5}$$

$$Y_{sonde}(i) = \sum_{j=-5}^{j=5} y_{sonde}(j)\ . \tag{6}$$

Since the radiosonde raw data $x_{sonde}(j)$, $y_{sonde}(j)$ are available in 2-s intervals this represents a 20-s smoothing of the position data prior to differencing for the winds. The wind differencing for the radiosonde is identical to the radar Eqs. (3) and (4).

There was no common time base between the two systems so it was necessary to shift the two wind sequences of 6-s winds, radar and sonde, in time. This was accomplished on a computer where the sequences were displayed as two graphs (time vs $u_{rad}(i)$ and $u_{sonde}(i)$, time vs $v_{rad}(i)$ and $v_{sonde}(i)$. Figures 2a and 2b show an example prior to shifting. In addition the statistics (Number of pts, variance, mean, and max diff) were presented to help in alignment prior to the final statistics being recorded. Figures 3a and 3b show the same example after shifting. Figure 4 shows the difference between the radar wind values and the radiosonde wind values. The difference in the u components, on the right, have been given a +2 m/s offset while the v components have a -2 m/s offset, to avoid confusion. Figures 5 and 6 show histograms of the u and v differences respectively. Figure 7 shows the differences between the two radar tracks for comparison with the differences between sonde and radar Figure 4. Figures 2 through 7 are all for ascent 8, system 2.

5. RESULTS

The results are given in Table 2 as rms errors in m/s for each system and each ascent for both the u and v components and the vector sum of the components. In addition the difference of the vector rms's from system 1 and system 2 are given where appropriate. There are five flights with a single sonde tracked by both Loran ground sets and radar 5. The average vector error using system 1 is 0.327 m/s and using system 2, 0.333 m/s. If we include all ascents using one sonde and two Loran ground tracks, regardless of radar, we have seven cases and an rms vector error of 0.323 m/s for system 1 and 0.320 m/s for system 2.

Using all the ascents (10) and the system 2 data the rms vector error is 0.317 m/s. The average mean difference using these same 10 ascents with system 2 was 0.0953 m/s in the u axis and 0.0220 m/s in the v axis. Two flights were tracked by both radars. The average vector rms differences between the two radars was 0.078 m/s which if the error is ascribed equally would be 0.055 m/s per radar. The average mean difference was 0.002 m/s or less per axis for these radar data.

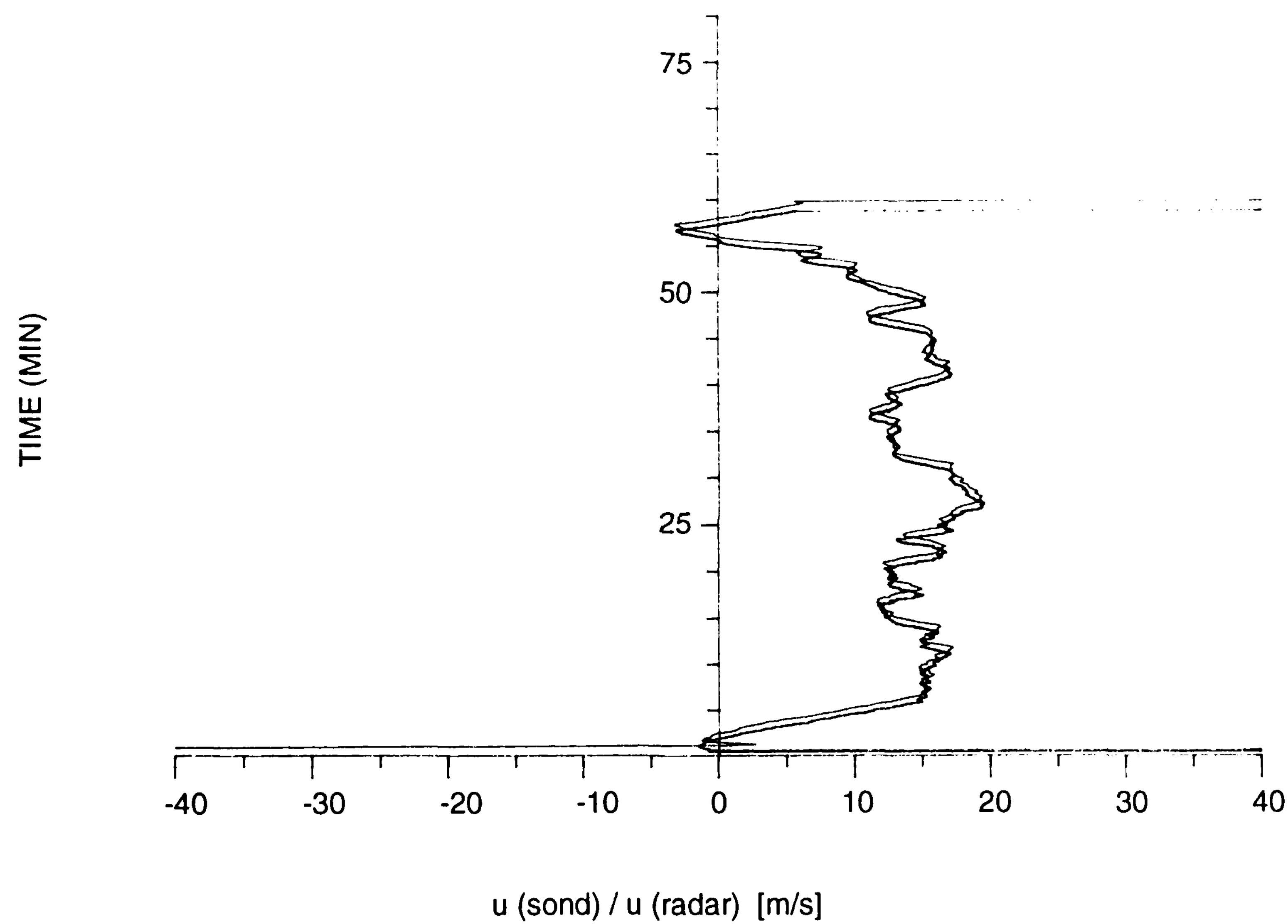

Figure 2a. u_{rad} + u_{sonde} vs Time (Before Aligning)

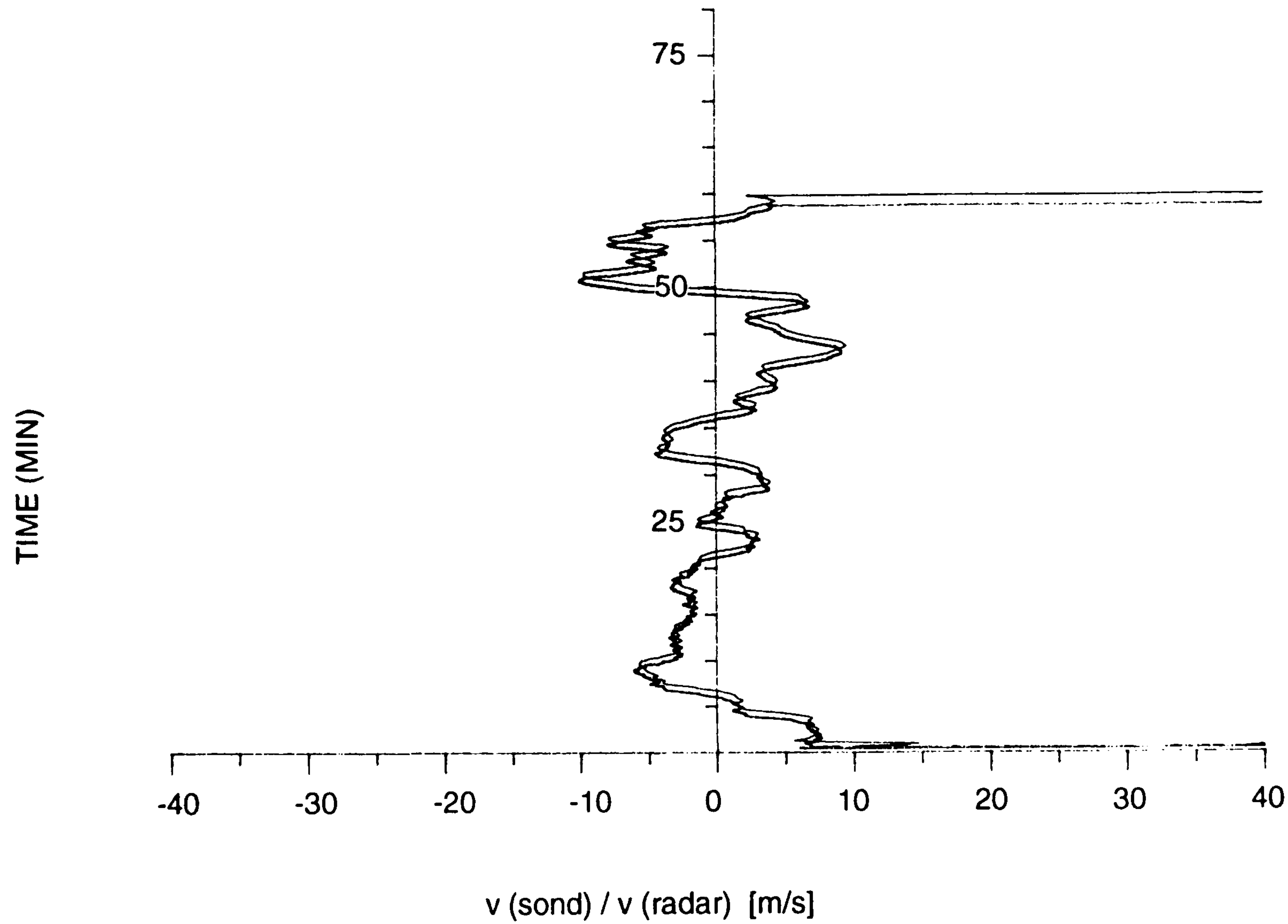

Figure 2b. $v_{rad} + v_{sonde}$ vs Time (Before Aligning)

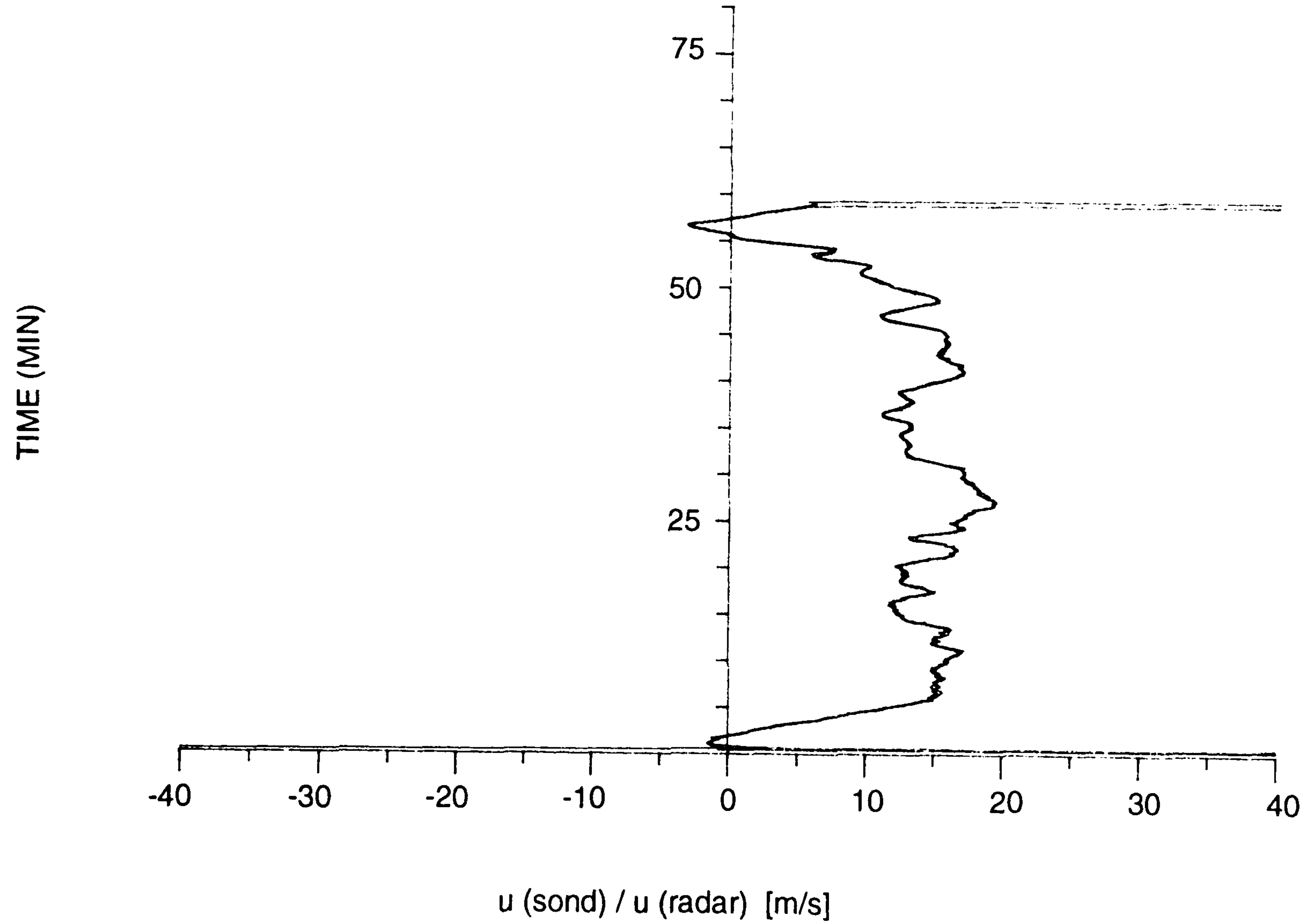

Figure 3a. $u_{rad} + u_{sonde}$ vs Time (After Aligning)

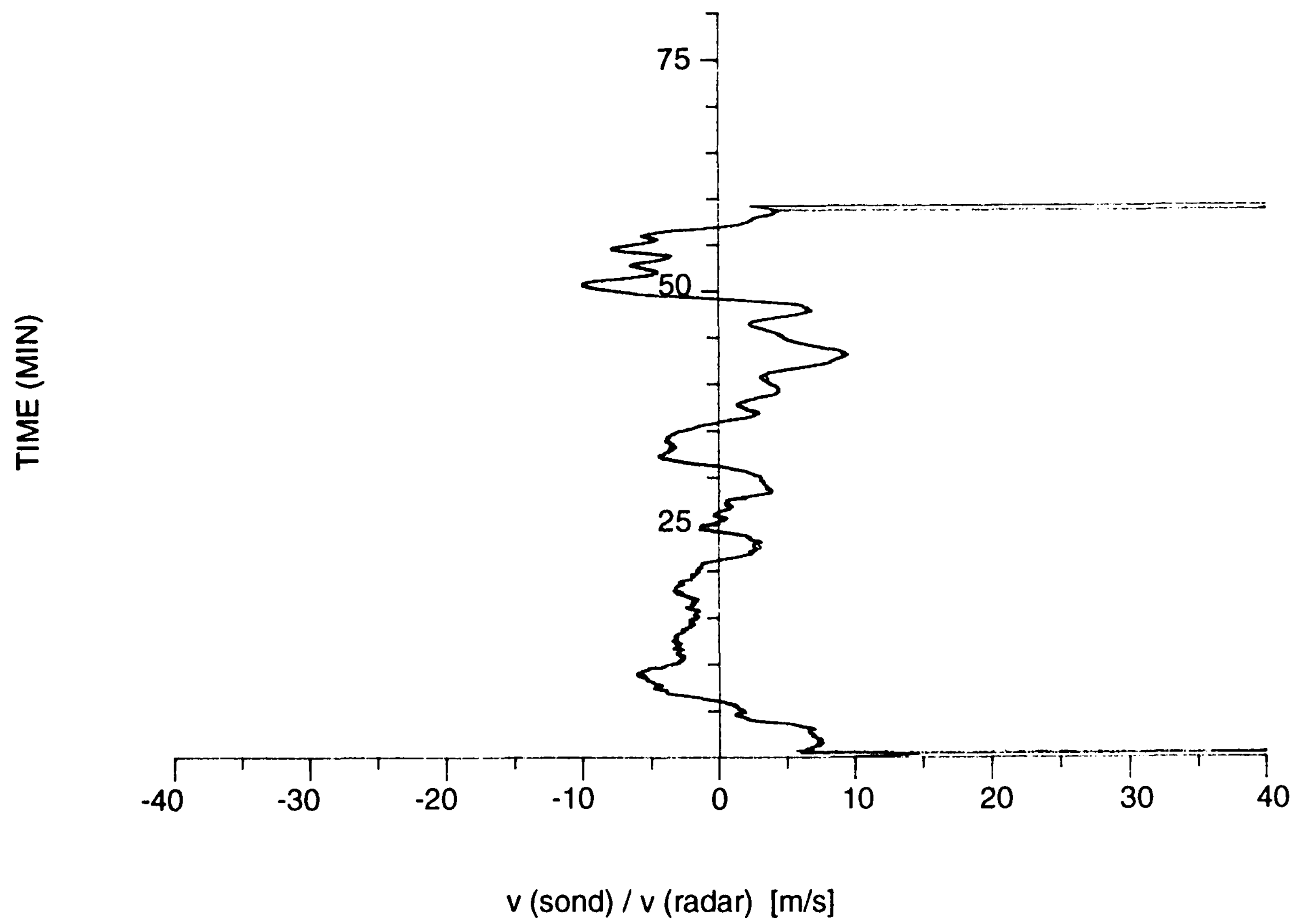

Figure 3b. $v_{rad} + v_{sonde}$ vs Time (After Aligning)

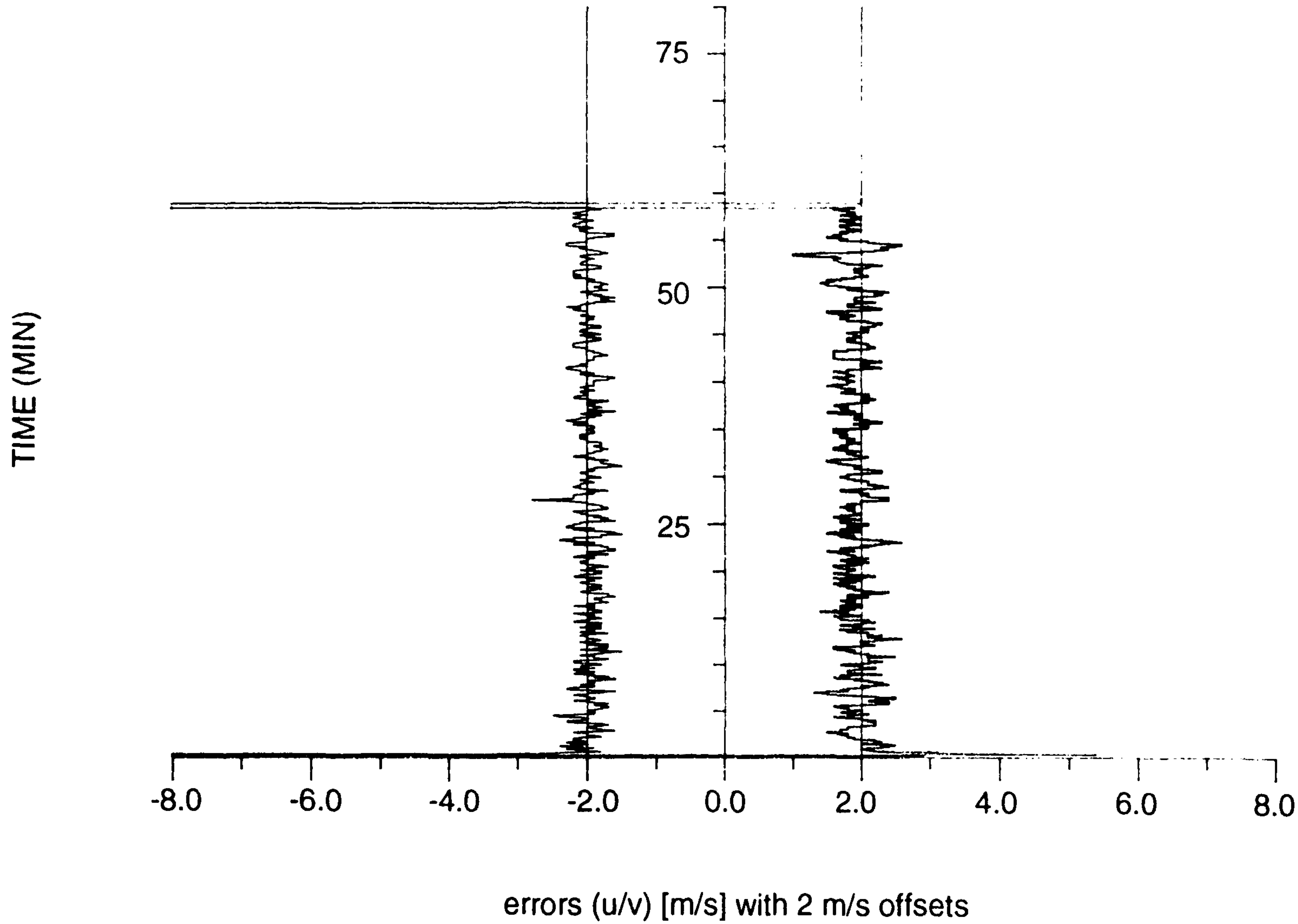

Figure 4. $(u_{rad} - u_{sonde}) + (v_{rad} - v_{sonde})$ vs Time

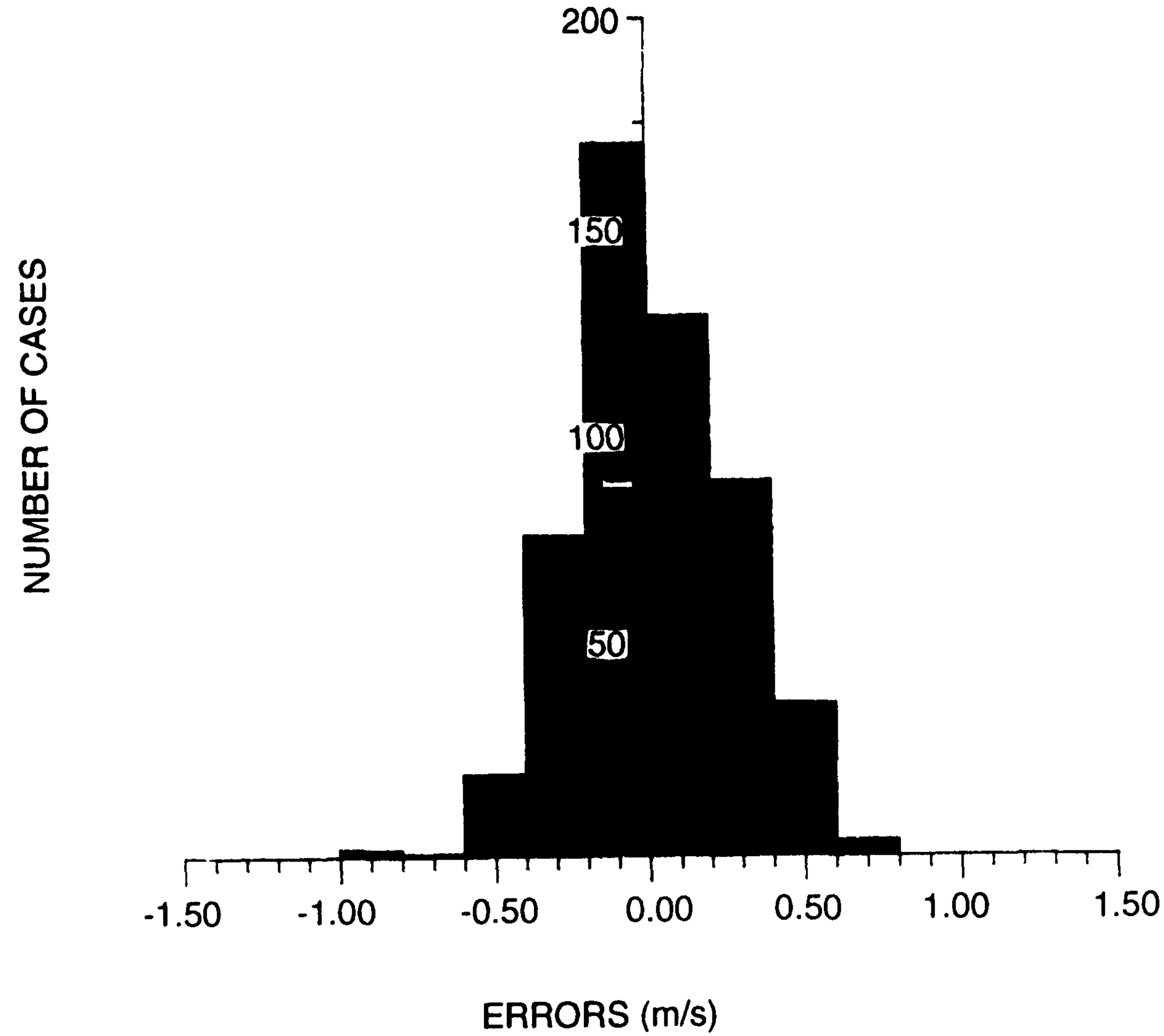

Figure 5. Histogram of ($u_{rad} - u_{sonde}$)

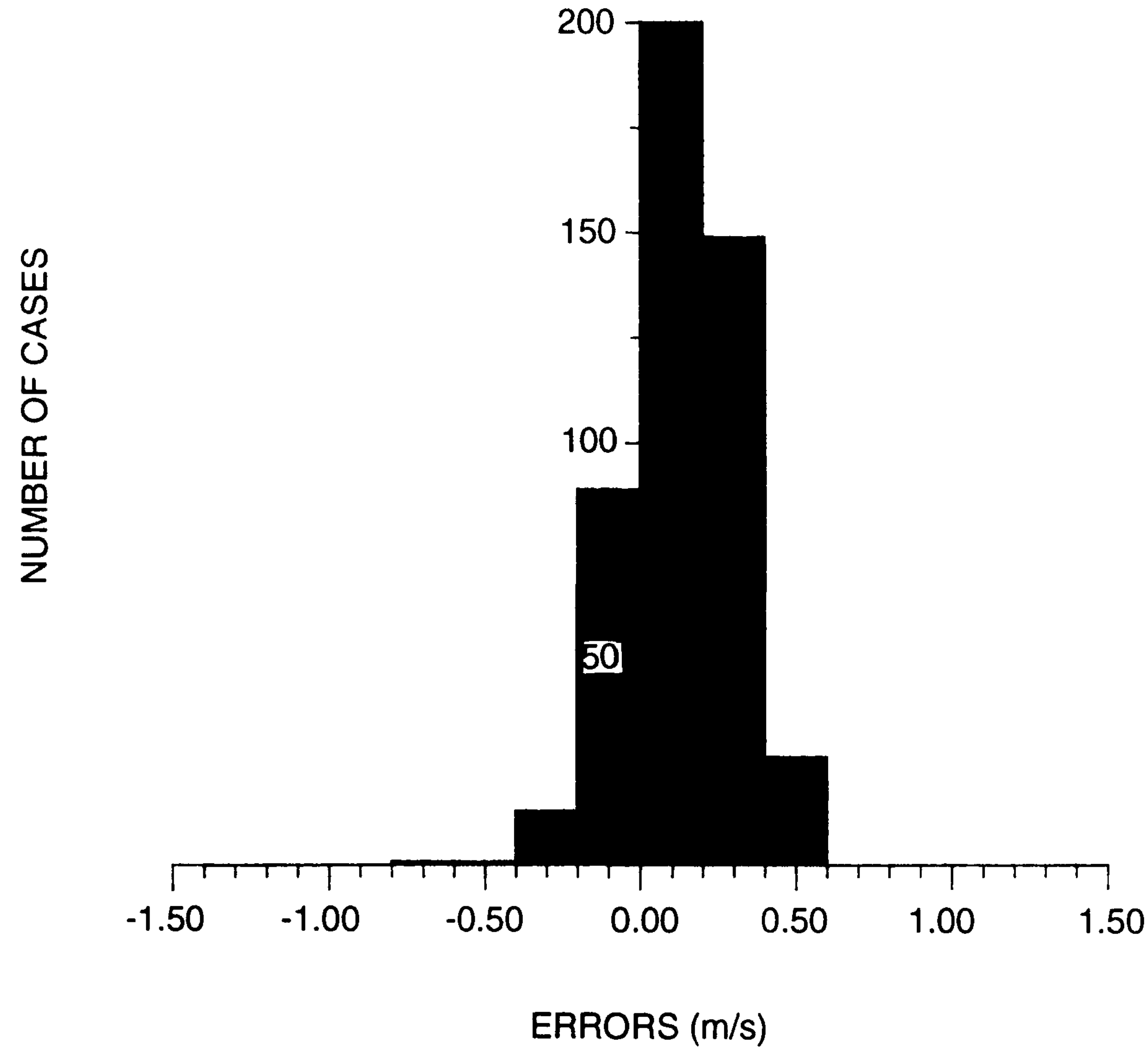

Figure 6. Histogram of ($v_{rad} - v_{sonde}$)

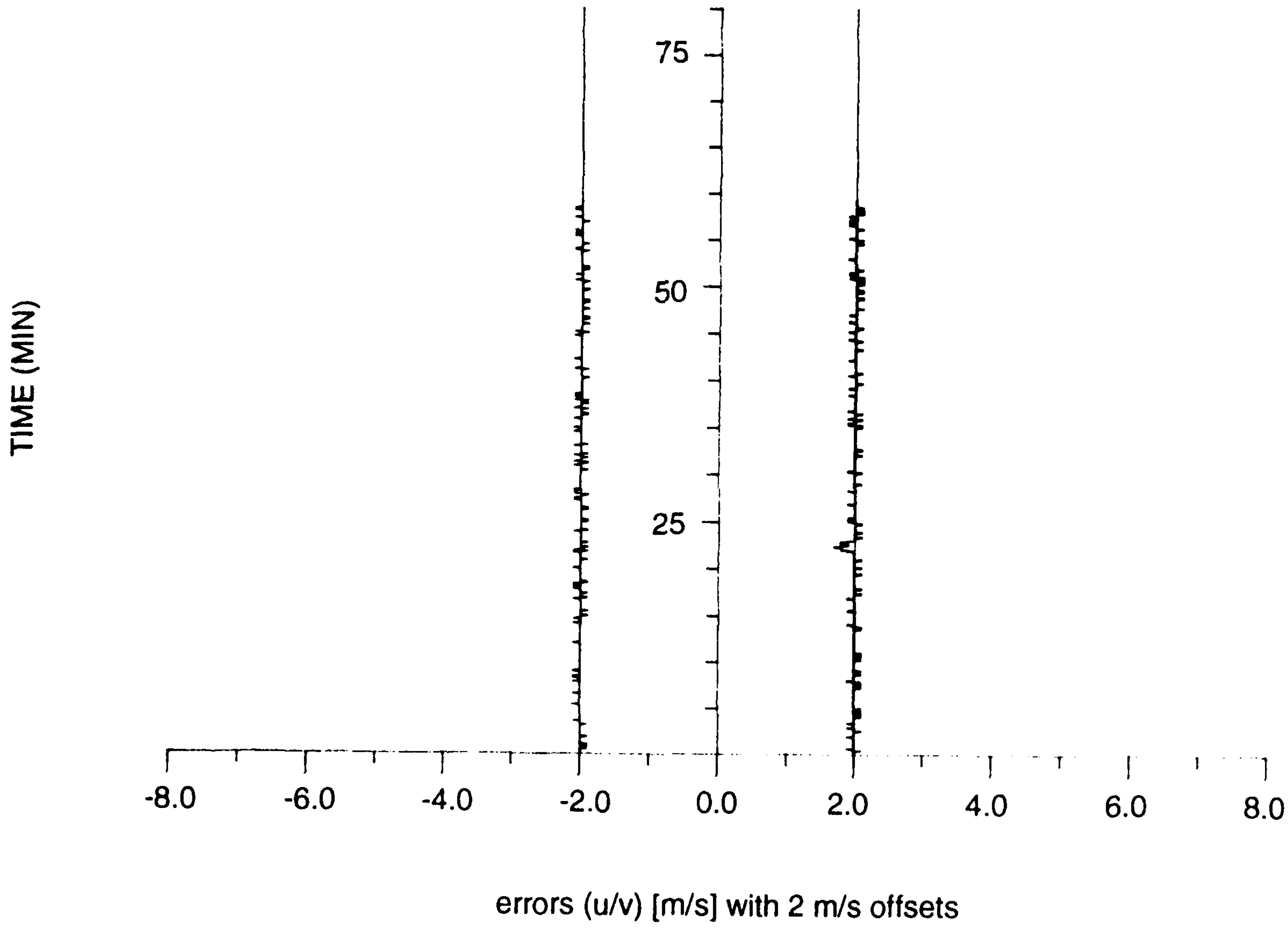

Figure 7. $(u_{rad5} - u_{rad3}) + (v_{rad5} - v_{rad3})$ vs Time

Table 2. Results

		System 1				System 2		
Ascent Number	Radar Number	u rms	v rms	Vector rms	Diff Vector rms	u rms	v rms	Vector rms
1	5	0.220	0.186	0.288	0.061	0.248	0.245	0.349
2	5	0.286	0.221	0.361	0.003	0.300	0.206	0.364
3	5	0.278	0.256	0.378	-.022	0.278	0.222	0.356
4	3	0.249	0.238	0.344	-.035	0.248	0.184	0.309
5	3	0.232	0.159	0.281	-.013	0.224	0.147	0.268
6*	5	0.204	0.159	0.259	0.076	0.268	0.201	0.335
7	5	0.201	0.194	0.279	0.008	0.226	0.177	0.287
8	5	0.279	0.172	0.328	-.020	0.252	0.177	0.308
8	3	0.282	0.174	0.331	-.020	0.256	0.177	0.311
9	5					0.302	0.180	0.352
9	3					0.298	0.180	0.348
10	3					0.273	0.209	0.344

* Separate sondes for system 1 and system 2.

The appendix contains a more complete listing of statistics for each flight on which this table is based.

6. CONCLUSIONS

These tests show an overall rms vector difference of 0.32 m/s between winds obtained using a Loran system and winds derived using tracking radars at GSFC/Wallops Flight Facility. The difference between winds derived using the two radars tracking the same sonde results in an rms vector difference of 0.055 m/s per radar. This radar uncertainty accounts for only 0.005 m/s of the 0.32 m/s difference between the sonde and radar. Both the radar and sonde winds represent position differences 1 minute apart. This represents approximately 350 meter vertical resolution. The radar position data used in these calculations were generated by averaging 5 s of data while the sonde position data represents 20-s averages.

There were two ground stations tracking a single sonde and there appears to be no significant difference due to the ground station used (0.328 vs 0.323 m/s). There was only one ascent where different sondes were tracked by each ground station. The difference (0.076 m/s) in the rms vector

differences was much larger than the differences when tracking the same sonde, but the magnitude is unimportant in terms of radiosonde accuracies.

The accuracy of the radiosonde (0.32 m/s) is sufficient to use for evaluating the profiler since its variance (0.102 m^2/s^2) would be only 1/10th of the variance (1.0 m^2/s^2) budget needed to demonstrate whether the profiler can meet a 1.0 m/s requirement.

Appendix A

Sonde/Radar Statistics

Table A1. Sonde/Radar Statistics

							u-Component					v-Component				
DATE	TIME	ASC	RAD	SONDE	SYS	OBS	VAR	S.D.	MEAN	MIN	MAX	VAR	S.D.	MEAN	MIN	MAX
6/5/90	1310	1	5	1	1	589	0.041	0.201	-0.090	-0.7	0.7	0.033	0.182	0.038	-0.5	0.7
					2	849	0.051	0.225	-0.104	-1.0	0.5	0.060	0.245	-0.006	-0.7	0.7
	1645	2	5	2	1	633	0.072	0.268	-0.099	-0.7	0.8	0.048	0.218	-0.034	-0.8	0.5
					2	623	0.080	0.283	-0.100	-0.9	0.8	0.042	0.204	-0.030	-0.7	0.6
	1830	3	5	3	1	662	0.066	0.258	-0.103	-0.9	0.8	0.066	0.256	-0.001	-1.0	0.7
					2	764	0.065	0.256	-0.108	-0.9	0.7	0.049	0.222	0.010	-0.7	0.6
6/6/90	1309	4	3	4	1	685	0.057	0.239	-0.070	-0.8	0.6	0.056	0.236	-0.033	-0.7	0.9
					2	695	0.055	0.235	-0.080	-0.7	0.7	0.033	0.183	0.021	-0.6	0.7
	1438	5	3	5	1	710	0.049	0.220	-0.074	-0.8	0.6	0.025	0.159	0.006	-0.5	0.5
					2	710	0.044	0.209	-0.080	-0.7	0.6	0.022	0.147	0.004	-0.6	0.6
	1710	6	5	6a	1	835	0.033	0.180	-0.095	-0.7	0.4	0.025	0.159	0.011	-0.4	0.6
				6b	2	832	0.061	0.248	-0.102	-0.9	0.9	0.040	0.201	0.010	-0.5	0.7
	1858	7	5	7	1	550	0.035	0.186	-0.077	-0.7	0.5	0.037	0.193	-0.015	-0.6	0.6
					2	410	0.048	0.220	-0.051	-0.6	0.5	0.031	0.176	-0.023	-0.5	0.4
6/8/90	1601	8	5	8	1	563	0.071	0.267	-0.082	-1.9	1.0	0.029	0.171	0.020	-0.6	0.4
			3			563	0.076	0.275	-0.082	-1.9	1.0	0.030	0.173	0.020	-0.6	0.5
			5		2	575	0.057	0.238	-0.082	-1.0	0.6	0.030	0.173	0.037	-0.8	0.5
			3			575	0.059	0.243	-0.081	-1.0	0.7	0.030	0.173	0.036	-0.7	0.5
	1721	9	5	9	2	554	0.069	0.263	-0.148	-1.3	0.8	0.030	0.174	0.045	-0.4	0.6
			3			554	0.067	0.260	-0.146	-1.3	0.8	0.030	0.174	0.046	-0.4	0.6
	1838	10	3	10	2	632	0.065	0.255	-0.098	-0.9	0.8	0.042	0.206	0.034	-0.5	0.8